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THE BASIC MASSIVE ROCKS OF THE LAKE SUPERIOR REGION.

Introduction.—Before the application of the microscope as a geological instrument the classification of rocks was dependent largely upon their apparent similarities and dissimilarities as noted by the unaided eye. When the use of this instrument became almost universal it was found that many rock types similar macroscopically were very different from each other in microscopic appearance, and very dissimilar genetically, while many of the apparently dissimilar types were discovered to owe their differences in appearance simply to the ordinary processes of weathering, which masked their original essential characteristics with the products of mineral alteration.

The rocks now known as gabbro are quite well characterized by peculiarities that are strikingly uniform in their essential features, though formerly the term was made to cover a large number of closely related but quite different rock types. Their history affords a good illustration of the manner in which rock classification developed from its early independent form to its present highly differentiated but well defined one.

In the case of the gabbros, as well as in the case of other rock groups, there were at first included under one name all rocks whose superficial features were similar to those of the type originally described. Later, more discriminating study separated this group into a large number of subordinate groups, based on

slight differences noted in the characteristics of their components. The number of such groups became larger and larger until eventually there were almost as many sub-groups recognized as there were students who had investigated them. Thus the classification grew complicated, because the criteria upon which it was based were mainly unessential, though prominent, peculiarities in the components comprising the classified bodies. The next step, following the use of the microscope in rock investigation, consisted in the consolidation of several sub-groups into one larger group—a result due directly to the comparative ease with which the microscope enables the student to distinguish between the primary and secondary—the essential and unessential—properties of rocks. After careful work of this kind had finally established the various varieties on the basis of mineralogical composition, attention was directed to the manner in which the rock components are associated—to the rock structure—and an explanation of variation in structure was sought in the environment of rock masses. The study ot the gabbros thus became a geological study rather than a mineralogical one.

The brief historical sketch of the classification of the granular basic rocks, with special reference to the differentiation of the gabbros from the remainder of the group, will thus serve to illustrate the successive steps with which rock classification in general has progressed. But the sketch is not offered here solely as an illustration of the development of rock classification. It was originally written with a view of emphasizing the distinctive differences between the gabbros and the coarse diabases. In the Lake Superior region there exist many coarse basic rocks that have been called indiscriminately "gabbros." Some of these possess the features of true gabbros, as defined by a study of the history of this group of rocks, and others the peculiarities of diabases. Until the distinction between these two types is clearly recognized, it will be impossible to discuss the causes of their differences. It is hoped that the present contribution will serve partly to clear the ground for a careful study of the coarse basic eruptive rocks of the Lake Superior

province, which the writer desires to make as opportunities and time permit. The present plan proposes a series of papers appearing in this Journal at irregular intervals. The first follows this introduction. The second will embrace a sketch of previous work on the basic rocks of the region, and the succeeding ones will treat of the gabbros and coarse diabases in the Huronian and Keweenawan areas on both sides of the lake.

I. BRIEF HISTORY OF THE CLASSIFICATION OF THE GABBROS AND NEARLY RELATED ROCKS.

At about the same time the names Euphotide and Gabbro were applied, respectively by Haüy[1] in France and von Buch[2] in Germany, to rocks composed essentially of a foliated augite and a "compact feldspar." Haüy describes the Euphotides as consisting of a compact feldspar and diallage, for which combination he constructed the name from the two Greek words εν (blessed) and φῶς (light), in allusion to the green and white mottling in the hand-specimens from many localities. Von Buch's name, gabbro, was adopted from the Florentines[3] to cover a group of rocks that had been described at various times under a great number of different names, of which perhaps jade was the most common. Although gabbro was used by the Italians to designate what is now known as a diallagic serpentine, it has been accepted by nearly all geologists outside of France as the name to be applied to the group of rocks which von Buch so clearly and definitely separated from other allied rocks, and defined as made up of jade, feldspar and smaragdite.

Between the time of the appearance of von Buch's paper and the publication of the first microscopic description of gabbros by Rose in 1867,[4] many descriptions of these rocks appeared in

[1] Traité de Mineralogie, 2d Ed., IV., p. 535.

[2] Ueber den Gabbro, mit einigen Bemerkungen über den Begriff einer Gebirgsart. Geol. natur. f. Freund. zu Berlin, Mag. etc., 1810, IV., p. 128; 1816, VII., p. 234.

[3] Cf. T. S. HUNT: Contributions to the History of Euphotide and Saussurite. Am. Jour. Sci., 2d Series, Vol. XXVII., 1859, p. 336.

[4] G. ROSE.—Ueber die Gabbroformation von Neurode in Schlesien. Erster Theil. Zeits. d. deuts. Geol. Ges. XIX., 1867, p. 270.

the various geological journals. In 1835 Gustav Rose[1] separated the rocks composed of labradorite and hypersthene, with accessory olivine, mica, apatite and ilmenite, from the gabbros, and included them under the name "Hypersthenfels," at the same time suggesting that the term gabbro be confined to rocks containing labradorite and diallage. Many rocks were described as hypersthenites or hypersthene rocks, because of the supposition that the highly foliated augite in them really belonged to this variety of pyroxene. Delesse[2] and others showed that the compact feldspar of Haüy, and the jade mentioned by von Buch as an essential constituent of gabbros (afterwards called saussurite by de Saussure Jr., and by Beudant) is in some cases a true plagioclase; and Hunt[3] showed that in other cases it consists of zoisite, of white garnet mixed with serpentine, or of meionite, and that the rocks containing these substances usually also contain hornblende, with the characteristics of Rose's uralite. Hunt, further, declines to regard the rocks containing a triclinic feldspar and pyroxene (either augite, hypersthene or diallage) as true gabbros. He places them among the dolerites, and declares that the true euphotides described by Haüy and de Saussure are mixtures of *smaragdite* and saussurite; a declaration that Cocchi[4] made for the Tuscan rocks a few years later. Rocks composed essentially of diallage and saussurite Cocchi called granitones. Whatever may be the virtue of the objections raised to the use of the name gabbro for plagioclase-diallage rocks, it still continued[5] to be applied to rocks thought to be of this composition, just as hypersthenfels or hypersthenite

[1] Ueber die Gebirgsarten, welche mit den Namen Grünstein und Grünsteinporphyr bezeichnet werden. Poggendorf's Annalen, XXXIV., 1835, p. 16.

[2] Recherches sur l' Euphotide. Bull. Soc. Géol. d. France, VI., 1848-49, p. 547.

[3] T. S. HUNT.—On Euphotide and Saussurite. Am. Jour. Sci., 2d Series, Vol. XXV., 1858, p. 437; and Contributions to the History of Euphotide and Saussurite. Ibid., XXVII., 1859, p. 326.

[4] I. COCCHI.—Description des roches ignées et sedimentaires de la Toscane dans leur succession géologique. Bull. Soc. Géol. d. France (2) XIII., 1856, p. 267.

[5] Cf. P. KEIBEL.—Analysen einiger Grünsteiner des Harzgebirges. Zeits. d. deutsch. geol. Ges. IX., 1857, p. 569.

was used to designate those in which hypersthene was supposed to occur.[1]

When Naumann[2] wrote the chapter on rocks for the second edition of his "Lehrbuch der Geognosie" he defined the gabbros as characterized by the possession of labradorite or saussurite and platy augite, and divided them into two varieties—the gabbros, consisting of labradorite or saussurite, diallage and smaragdite, and the hypersthenites, containing hypersthene as the pyroxenic constituent, and sometimes a little secondary hornblende. Naumann recognized the difficulty of distinguishing between the gabbros and the diabases, even at this early day, before it was known that augite could have imposed upon it a parting as the result of pressure, for he says "Diese Familie würde sich vielleicht mit der nächstfolgenden des Diabases vereinigen lassen" (p. 573); and again, in a foot-note to diabase "Wenn der feldspathige Bestandtheil der Gesteine dieser Familie wirklich in allen Fällen Labrador wäre, so würde es zweckmässig sein, die Familie des Gabbro mit ihr zu vereinigen" (p. 578). The norites described by Scheerer[3] and Esmark, were thought probably to belong with the gabbros, but their true relations to the group were not known.

A few years later Kjerulf[4] discussed the results reached by himself and other Norwegian geologists, and ended by dividing the Norwegian rocks of the gabbro type into gabbros and norites, the former consisting of labradorite, augite, hornblende, and the latter of labradorite and diallage.

[1] VON RATH: Geognostische Bemerkungen über das Berninagebirge (?) in Graubündten. Ib. IX., 1857, p. 246.

RAMMELSBERG: Bemerkungen über den Gabbro von der Baste (Radauthal im Harz). Ib. XI., 1859, p. 101.

VON RICHTHOFEN: Geognostische Bechreibung von Süd-Tyrol. 1860, p. 146.

[2] Lehrbuch der Geognosie. B. I. 1860, p. 573-577.

[3] Geognostisch-Mineralogische Skizzen, gesammelt auf eines Reise an der Süd-küste Norwegens. Neues Jahrb. f. Min., etc., 1862, p. 668.

[4] Zusammenstellung der bisherigen Ergebnisse der geologischen Untersuchung Norwegens. Neues Jahrb. f. Min., etc., 1862, p. 144.

The macroscopic examination of the rocks of this type continued to give rise to many different methods of classifying them, but the general tendency after this time seems to have been toward the union of the gabbros and the hypersthenites into one group. Von Cotta,[1] for instance, embraces the gabbros hypersthenites and norites under the single head "gabbro,"[2] and then divides this group into five sub-groups—gabbros (granitone of Cocchi and other Italians), with labradorite or saussurite and diallage, or saussurite and smaragdite (gabbro of Cocchi, Hunt and others); euphotides, equivalent to the saussuritized gabbros of later authors; norites of Scheerer, which are regarded as gabbros containing a soda-orthoclase and some quartz; hypersthenites, consisting of plagioclase and hypersthene, and finally, Monzoni-hypersthenites, afterwards discovered by de Lapparent[3] to belong to an entirely different group since they contain no hypersthene.

In the same year in which von Cotta's classification appeared Aug. Streng[4] began the task of reducing the number of varieties that had been separated as distinct sub-groups of the general group gabbro. In his article on the gabbros and associated rocks in the Harz he describes the former as made up of labradorite, diallage, hypersthene, augite, hornblende, brown mica, and ilmenite. Of the hornblendic constituent he says, it is " Kein selbständiger Gementheil des Gabbro, und es werden daher durch ihre Anwesenheit keine besonderen Abänderungen erzielt." It is fibrous and is intergrown with the augite and diallage. The labradorite is saussuritized (p. 935) and the saussurite is therefore regarded as an unessential component. The hornblende-gabbros and the saussurite gabbros of the Harz

[1] Die Gesteinslehre. 2, Aufl. Freiberg, 1862.

[2] Cf. also Rocks Classified and Described. A Treatise on Lithology. By Bernhard von Cotta. An English edition by P. H. Lawrence, London, 1866.

[3] DE LAPPARENT: Sur la constitution géologique du Tyrol meridional. Annales des Mines. (6) VI., 1864, p. 259.

[4] AUG. STRENG: Ueber Gabbro und den sogenannten Schillerfels der Harzes. Neues Jahrb. F. Min., etc. 1862, p. 932.

are nothing but altered forms of the fresh gabbro. It is rather surprising to one accustomed to the use of the microscope as a means of studying rocks to learn that such correct conclusions as to the inner constitution of rock masses could be reached without the aid of this instrument as were reached by Streng in his study of these rocks.[1] A few years later the same geologist examined the gabbros and serpentines of Neurode in Silesia and discovered that all of the so-called hypersthene of these rocks is probably diallage, and that the serpentine rock, which from very early times had been known under the name of forellenstein, is really an altered gabbro, containing but a small amount of pyroxene. While Streng was examining the rocks of Silesia and deciding that the so-called hypersthenite is a true gabbro, Des Cloizeaux,[2] was investigating the hypersthenites and gabbros of France, with a view to their better classification. Des Cloizeaux declared as the result of his investigations that diallage, which is only a lamellar augite, and saussurite form euphotides and gabbros, and that many rocks that had been called hypersthenites or hyperites contain no hypersthene, but that the supposed hypersthene is diallage. He further proposes that distinctions between gabbros and hypersthenites be made more clear by the use of the name diallagite for labradorite and diallage rocks, and hyperite for those composed of labrodorite and hypersthene or bronzite. Although the use of Des Cloizeaux's name diallagite was not accepted by petrographers, all workers acknowledged the correctness of the statement that very many of the hypersthenites described from various localities are nothing more than gabbro in which the cleavage of the diallage is well marked.

Thus far the study of the gabbros and related rocks had proceeded without the aid to be obtained from the microscope. Many rocks had been described as belonging to the gabbro-type,

[1] A. STRENG: Ueber den Serpentinfels und Gabbro von Neurode in Schlesien. Neues Jahrb. f. Min., etc., 1864, p. 257.

[2] ALF. DES CLOIZEAX: Sur les Classifications des roches dites hyperites et euphotides. Bull. Soc. Geol. d. Fr. XXI, 1864, p. 105.

as defined by von Buch, and these had been given distinct names in accordance with the usual custom of distinguishing between the different varieties of a rock containing different characteristic mineralogical components. The years between 1860 and 1862, perhaps, marked the height of the wave of differentiation. After this time the classification of the numerous varieties took the direction along which it was to be carried farther by microscopical methods. Some of the hornblende gabbros, the forellenstein, many of the hypersthenites and some of the norites had been shown to be altered or fresh forms of true gabbros. The characteristics of the components of the two groups of the gabbros and the hypersthenites had been fairly well determined, and the similarity between many of the gabbros and the diabases had been pointed out.

The best résumé of the state of knowledge at this time concerning the rocks under discussion is to be found in Zirkel's [1] "Lehrbuch," published a year before the microscope was brought into use for the purpose of studying these rocks. Zirkel collected the observations of the different workers and incorporated them along with his own in such a way as to give an excellent impression of the value of macroscopic rock determinations, when undertaken by competent observers and aided by chemical analyses. He distinguishes as gabbros those rocks containing labradorite and diallage, at the same time agreeing with Bischof [2] in the view that the latter mineral is merely a variety of augite. Saussurite he regards as sufficiently characteristic of some gabbros to warrant their separation from others. He likewise looked upon smaragdite, which was thought to be an intergrowth of augite and green hornblende, as an essential constituent of some gabbros, and these he separated from the diallage gabbros under the name of smaragdite gabbros. The hypersthenites are described at some length, with the appended statement that many hypersthenites are probably gabbros. The

[1] F. ZIRKEL: Lehrbuch der Petrographie. Bonn, 1866, p. 112.

[2] BISCHOF: Lehrbuch der chemischen und physkalischen Geologie. Bonn, 1864. 2 Aufl. II, p. 654.

norites of Scheerer are classed among the gabbros and the hypersthenites, and those of Esmark are said to belong partly with these and partly with the diorites.

In the year succeeding the appearance of Zirkel's book, as has been stated, Rose[1] made the first microscopical examination of gabbros that has been recorded. He found among the Silesian gabbros two varieties, one of which is black and contains olivine, and the other green and free from olivine. Tschermak[2] followed Rose with a description of some Austrian gabbros, and an announcement that many serpentines are altered gabbros, and that Streng's forellenstein is only an olivine gabbro. He concluded, further, that augite and diallage differ only in physical properties, and therefore that gabbro "ist eine Abtheilung des Diabas" (p. 168).

In the few years succeding Tschermak's paper several contributions of great importance were added to the literature of the gabbros. Zirkel[3] recognized olivine varieties of these rocks among the Tertiary formations on the islands off the west coast of Scotland, and succeeded in showing that the hypersthenites described by Macculloch from the island of Skye contain no hyphersthene. He further pointed out as important the fact that the plagioclase associated with diallage is rich in inclusions, while that associated with ordinary augite is free from them. In the same year Hagge[4] continued the work that had been so ably begun by DesCloizeaux in 1864. He made a careful microscopic examination of all the important gabbro and hyphersthenite occurrences recorded, and reached a result very similar to that of Des Cloizeaux. He found that very many of the rocks

[1] G. ROSE: Ueber die Gabbroformation von Neurode in Schlesien, Erster, Theil. Zeits. d. deutsch. geol. Gessel. XIX, 1867, p. 270.

[2] Die Porphyrgesteine Oesterreichs aus der mittleren geologischen Epoche. Wien, 1869.

[3] F. ZIRKEL: Geologische Skizzen von den Westküste Schottland. Zeits. d. deutsch. geol. Gessell. XXIII, 1871, pp. 58 and 92.

[4] R. HAGGE: Mikroskopische Untersuchungen uber Gabbro und verwandte Gesteine. Kiel, 1871.

heretofore described as containing hypersthene, have none of this mineral in their composition. He divided the gabbros into those containing olivine and those without this constituent, and from the latter separated a group which he called saussurite gabbros, recognizing at the same time, however, that saussurite is an alteration product of labradorite. He described it as consisting "of small crystal needles, prisms and grains, which are colorless or light-green, and are scattered irregularly in a ground mass with the appearance of a colorless glass, which often forms clear patches in the saussurite" (p. 52).

Six years after Rose's description of the Neurode gabbro, and seven years after the appearance of Zirkel's masterly classification of rocks based almost entirely upon their macroscopic properties, the latter geologist was enabled to issue a second volume containing a classification of rocks based on the microscopical characters. In this volume[1] he defines the gabbros as granitic in structure, and consisting principally of plagioclase and diallage, usually with the addition of olivine. The plagioclase is usually labradorite. It usually contains fluid inclusions and numerous little dark needles and prisms arranged in a definite order. The diallage is filled with small brown plates and the olivine is characterized by thousands of fantastically shaped hair-like bodies. The structure of genuine gabbros is described as coarsely or finely granular. They contain no porphyritic crystals and no unindividualized ground mass.

The group of hyphersthenites had by this time become almost depleted of its members. Most of the hyphersthenites had been found to be diallagites, in the sense of Des Cloizeaux, so that but four undoubted occurrences of this rock were left to be included by Zirkel in the group. On the other hand, the number of "forellensteins" had increased to such a degree that a group was formed of the same classificatory value as that of the hypersthenite group. These rocks were described as having the structure of gabbros, while at the same time they contain but

[1] F. ZIRKEL: Mikroscopische Beschaffenheit der Mineralien und Gesteine. Leipzig, 1873.

little diallage. Their separation from the gabbros and the hypersthenites seems to be upon mineralogical grounds solely; since emphasis is laid upon the fact that their feldspar is apparently anorthite. Of such great importance was the mineral constitution of rocks regarded at this time, that we find no statement made with respect to the similarity between many diabases and many gabbros. The facts pointed out by earlier investigators to the effect that augite and diallage are but slightly different varieties of the same mineral, had been overlooked, or had, at any rate, been regarded as of little importance, since these expressions of opinion had for the most part not been founded on the study of thin sections. The microscope was used principally for the determination of the nature of the constituents of rocks, and had therefore emphasized their mineralogical composition out of due proportion to its importance.

The influence of Zirkel's book upon geologists in all parts of Europe was soon felt in the increased number of purely petrographical papers published in the journals; and this increased interest soon manifested itself in studies that included more than a mere description of rock sections. Vogelsang[1] had, years before, shown that there were great possibilities in the new science of petrography, but in the flush of excitement over the discovery of an easy and exact method of rock analysis, these possibilities were left unexplored until geologists became quite well acquainted with the essential components of the most important rock types.

Soon after the composition of the important rock types became fixed, attention was turned more particularly to their structure. Professor Judd[2] examined the gabbros in the denuded cores of Tertiary volcanoes in Scotland, and found that while diallage is the prominent pyroxene of the lower portions of the

[1] H. VOGELSANG: Philosophie der Geologie und Mikroskopische Gesteinsstudien. Bonn. 1867.

[2] J. W. JUDD: The Secondary Rocks of Scotland. Second Paper. On the Ancient Volcanoes of the Highlands and the Relations of their Products to the Mesozoic Strata. Quart. Jour. Geol. Soc., XXX. 1874, p. 220.

masses, in their upper portions the diallage is replaced in large part by augite. Many other papers of importance were published, and in most of these the structure of the rocks described was more or less briefly alluded to. Wiik[1] announced the fact that many of the Finnish rocks classed by Zirkel among the hypersthenites are olivine-diabases and olivine gabbros, while Stelzner[2] filled the gap thus produced in this group by the discovery of a bronzite gabbro from the Monte Rosa district in the north of Italy. Vallee-Poussin and Renard[3] made a thorough examination of the plutonic rocks of Belgium and the eastern part of France, and discussed the composition and structure of some gabbros.

The result of these and other workers were collected and edited by Rosenbusch[4] in his well-known book on the microscopical characters of massive rocks, in which the fixing of rock types which had been begun by Zirkel was carried out in a scheme which was not improved upon until the same author published the second edition of his treatise ten years later[5]. In the scheme proposed in 1877, the gabbros were placed among the pre-Tertiary massive granular rocks. The group was made to include all pre-Tertiary rocks consisting essentially of diallage and plagioclase in their unaltered state, either with or without olivine. Saussurite was recognized as a secondary product produced by the alteration of plagioclase, and green hornblende (actinolite and smaragdite) as the result of an alteration of diallage. The saussurite and the hornblende gabbros were no longer

[1] F. J. WIIK: Mineralogiska och petaografiska meddelanden. Ref. Neues Jahrb. f. Min., etc., 1876, p. 206.

[2] A. STELZNER: Briefliche Mittheilung. Zeitz. d. d. geo. Gessell., XXVIII. 1876, p. 623.

[3] Ch. de la VALLEE-POUSSIN, et A. RENARD: Memoire sur les caracteres mineralogiques et stratigraphiques des roches dites plutoniennes de la Belgique et de l' Ardenne francaise. Bruxelles, 1876, pp. 62–76 and 125–128.

[4] H. ROSENBUSCH: Mikroskopische Beschaffenheit der Massigen Gesteine. Stuttgart, 1877.

[5] H. ROSENBUSCH: Mikroskopische Beschaffenheit der Massigen Gesteine. 2te Aufl. Stuttgart, 1887.

regarded as sub-groups of the gabbro family, but were looked upon merely as altered gabbros. Magnetite and titanic iron oxide as well as apatite were mentioned as accessory in all members of the group, and hornblende, rhombic pyroxene, brown mica and quartz were spoken of as occurring in many (p. 459). The difficulty of distinguishing between a gabbro and a diabase was clearly appreciated. The distinction between diallage and augite, upon which is based the mineralogical distinction between gabbro and diabase, is acknowledged to be of doubtful value for this purpose, since some rocks with the other properties of gabbros have an augite devoid of the diallagic parting, while others with many of the properties of diabase possess an augitic constituent with the parting highly developed. "Höchstens dürfen sie (the gabbros) als ein unterabtheilung der Diabase, welche sich durch eine eigenthümliche Structur und Theilbarkeit ihres Pyroxens charakterisirem." The structure of the gabbros was said to vary within narrow limits. They are always coarse-grained rocks whose different structures depend principally upon the different amounts of their constituents. Since they are so well characterized by the monotony of their texture, and since no gradations[1] between them and porphyritic or glassy forms were known, while on the other hand the structure of the diabases varies so widely between holocrystalline and glassy, the former were regarded as a distinct rock type. Rosenbusch, however, declined to regard the gabbros as dependent for their individuality upon the mere possession of an augite with pinacoidal parting, but was inclined to look upon them as rocks occupying a position in the scheme of classification intermediate between that of the diabases and that of the norites, the latter

[1] MR. T. T. GROOM has recently described a gabbro glass associated with gabbro at Carrock Hill in the Lake District, England, under the name carrockite. Since this glass occurs only as a narrow selvage where the gabbro has cooled rapidly in contact with preëxisting rocks, it cannot be considered as contradicting the above general statement. The structure is not one connected genetically with the rock itself, but is a local phenomenon dependent upon extraneous circumstances. See T. T. Groom: On the Occurrence of a new form of Tachylyte in Association with the Gabbro of Carrock Fell, in the Lake District. Geol. Magazine. Jan. 1859, p. 43.

consisting of plagioclase and an orthorhombic pyroxene, and therefore corresponding in part to Zirkel's hyphersthenites. The principal difference between the gabbros and diabase was, then, one of structure, while subordinate to this was a difference in mineralogical composition. In his sentences closing the discussion of the gabbros Rosenbusch writes: "Man müsste aber alsdann das Hauptgewicht für die Absonderung der Gabbros nicht auf den eigenthümlich struirten Diallag legen, sondern darauf, dass sie einen pinakoidal spaltbaren klinorhombischen Pyroxen als wesentlichen und daneben einen rhombischen Pyroxen als accessorischen Gemengtheil enthielten." The distinction here made is evidently a strained one, for quite a number of gabbros were known in which the structure is the typical gabbro structure, while at the same time they are entirely free from rhombic pyroxenes. The new group name "Norites" is borrowed from Esmark and Scheerer, although the rocks described by these geologists are by no means typical of the group. The advantage of the name over "hyphersthenite" is readily appreciated when it is remembered that the rhombic pyroxene of these rocks is not always hypersthene.

The publication of Rosenbusch's classification of the massive rocks fixed the characteristics of the various types with some degree of scientific accuracy. There was, however, much to be learned concerning the less well known types, and much more to be discovered concerning the relations of the various types to each other.

The work of Judd, referred to above, was the beginning of a severe attack on the wavering line of geologists who still clung to the belief that mineralogical differences alone should determine the class to which a rock should be referred. It would be unprofitable in the present place to mention all of the important articles treating of gabbros and their varieties. It will be sufficient for our purposes to refer briefly only to those papers in which new types of gabbro are described and a little more fully to those which treat of the classification of these rocks.

The existence of true hyphersthenites (norites), of gabbros,

and of types intermediate between these, was established at the time that Rosenbusch's book appeared. In this year (1877) Törnebohm[1] suggested that the name hyperite be used for the latter classs, composed essentially of plagioclase, diallage and an orthorhombic pyroxene, that the term gabbro should be used to designate plutonic rocks in which the pyroxene is diallage, and that hyphersthenite (or norite) should be restricted to those containing a rhombic pyroxene as their principal augitic constituent. This suggestion has not met with a very wide acceptance because the gradation between the three types is very gradual, and in all cases the geological relations of the types are the same. It is convenient, however, as a descriptive name for those gabbros containing two pyroxenes.

In the same year Streng[2] investigated the crystalline rocks of Minnesota and described a gabbro from near Duluth, in that State, to which he gave the name hornblende-gabbro, because of the supposition that the brown hornblende it contains is primary. Irving,[3] however, has shown that much of the brown hornblende in the rocks of the Lake Superior region is secondary. He thought that nearly all, if not all, of the hornblende of the hornblende gabbros is of this nature. Williams[4] has also shown that compact brown hornblende is often a secondary product of the alteration of augite; and Wadsworth[5] holds to the view that this is the character of all the hornblende in the Lake Superior gabbros.

[1] A. E. TÖRNEBÖHM: Ueber die wichtigsten Diabas und Gabbrogesteine Schweden. Neues Jahrb. f. Min., etc., 1877, p. 387.

[2] A. STRENG and J. H. KLOOS: Ueber die krystallinischen Gesteine von Minnesota in Nord Amerika. Neues Jahrb. f. Min., etc., 1877.

[3] R. D. IRVING: On the Paramorphic Origin of the Hornblende of the Crystalline Rocks of the Northwestern States. Am. Jour. Sci., Vol. XXVI, 1883, p. 27; Ib. XXVII, 1884, p. 130.

[4] G. H. WILLIAMS: On the Paramorphosis of pyroxene to hornblende in Rocks. Am. Jour. Sci., XXVIII, 1884, p. 259.

[5] M. E. WADSWORTH: Preliminary Description of the Peridotytes, Gabbros, Diabases and Andesytes of Minnesota. Bull. No. 2. Geol. and Nat. Hist. Surv. of Minn., St. Paul, 1887, p. 66.

If Irving, Williams, and Wadsworth are correct in their opinion, the hornblende-gabbro of Streng is merely an altered form of gabbro, and therefore it does not deserve a distinctive name (except for the mere purpose of description), any more than do the saussurite-gabbros.

Another type of gabbro to which a distinctive name has been given is also found in the region surrounding Lake Superior. This is an orthoclase-gabbro which has been carefully described by Professor Irving. An unstriated feldspar taken to be orthoclase had been discovered in gabbros from European localities by various petrographers, but it was usually present in such small quantity that but little importance was attached to it. In this country Pumpelly[1] and Julien[2] identified orthoclase in certain gabbros from Wisconsin, and Irving[3] discovered it in similar rocks from both Wisconsin and Minnesota. The latter author describes the orthoclase as often reddened and charged with secondary quartz. He mentions in detail the characteristics of the rocks containing it, and regards the differences noted between these and the non-orthoclastic gabbros as of sufficient importance to warrant their separation from the latter under the variety name orthoclase-gabbro.

Within the past few months still an additional gabbro variety has been brought into prominence by Adams[4] and by Lawson[5] working in different portions of North America. This consists essentially of plagioclase with gabbro characteristics, with which is associated only now and then a grain of pyroxene or magnetite. It differs from "forellenstein" in containing no olivine, and from

[1] R. PUMPELLY: Geology of Wisconsin, III, 1880, pp. 38, 40, 41.

[2] A. A. JULIEN: Microscopical Examination of eleven rocks from Ashland County, Wisconsin. Geol. of Wisconsin, III, 1880, p. 233.

[3] R. D. IRVING: The Copper-Bearing Rocks of Lake Superior. U. S. Geol. Survey, Monograph V, pp. 50–56.

[4] F. D. ADAMS: Ueber das Norian oder ober-Laurentian von Canada. Neues. Jahrb. f. Min., etc. B.B. VIII, p. 419.

[5] A. C. LAWSON: The Anorthosytes of the Minnesota Coast of Lake Superior. Geol. and Nat. Hist. Surv. of Minn. Bull. No. 8, p. 1.

gabbro proper in the absence of diallage and orthorhombic pyroxenes. To this variety belong the norite[1] of New York State, the labradorite rock of Labrador, and the "anorthite rock" of Irving[2] from the north shore of Lake Superior.

But if we are to regard the anorthosites as gabbros in which pyroxene and olivine are wanting, we must pass to the other end of the series and include in the gabbro group those rocks in which plagioclase is wanting, and in which the sole essential components are pyroxene and olivine, or the pyroxenes alone — the peridotites of most authors and the pyroxenites of Williams.[3] Judd[4] has shown conclusively that the peridotites of Scotland are but phases of the gabbro with which they are associated, consequently they may with good reason be included within the gabbro group. But other peridotites and many of the pyroxenites must be regarded as distinct rocks. They are the products of the cooling of magmas of an essentially different composition from that of the gabbros, hence their consideration may well be excluded from this history.

The varieties of gabbro that depend upon mineralogical com position, so far as known, have been carefully described and named by their investigators — the names referring for the most part to the nature of their iron-bearing constituents. These are gabbro and olivine-gabbro, hyperite, norite, peridotite and pyroxenite, together with the alteration products of the first named, viz.: hornblende, saussurite, orthoclase, and perhaps quartz-gabbro,[5] the latter of which is more properly a quartz norite, since it contains no diallage. The varieties whose names have reference to

[1] Cf. F. D. ADAMS: l. c., p. 475 and 483.

[2] R. D. IRVING: Copper-Bearing Rocks of Lake Superior. Mon. V. U. S. Geol. Survey, p. 438.

[3] G. H. WILLIAMS: The non-Feldspathic Intrusive Rocks of Maryland and the course of their Alteration. Amer. Geologist, VI, 1890, p. 95. Not the pyroxenites of the French authors, which are mainly augite gneisses or schistose gabbros.

[4] J. W. JUDD: On the Tertiary and older Peridotites of Scotland. Quar. Jour. Geol. Soc., XLI, 1885, p. 357.

[5] Cf. U. S. GRANT: Note on the Quartz-Bearing Gabbroin Maryland. Johns Hopkins Univ. Circ. No. 103.

the feldspathic component are the orthoclase-gabbro of Irving and the eukrites[1] of the older authors. The latter name was proposed to designate rocks whose feldspar is anorthite. It never received a very wide application owing partly to the difficulty of distinguishing positively anorthite from the other plagioclases. Since the discovery by Tschermak that the plagioclases form a series of isomorphous compounds, the value of the distinction recognized by the name has disappeared and the name itself has fallen into disuse.

In addition to these there are two other varieties that seem to be sufficiently well characterized to deserve special names. One of these, the anorthosite, consists exclusively of gabbroitic plagioclase and the other "forellenstein" contains olivine and plagioclase.

During the past few years nearly all the work on the gabbros has tended toward the separation of these rocks from the diabases by sharper lines than those based merely on mineralogical distinctions. All those who had attempted to separate the two groups by the methods in use had failed, and some had thought it well to include the two in one group. The views of the earlier petrographers on this subject have been referred to. Later petrographers have accorded with these in their recognition of the fact that the value of the pinacoidal parting of diallage is not of great importance for the purpose of rock classification. The discovery of Judd, referred to above, produced a marked effect on the work of those who followed him in the same field.

In 1883 J. Roth[2] declared that the position of the gabbros with respect to the diabases depends upon the signification given to diallage. If we regard it as an altered augite with a pinacoidal parting produced by twinning it is found, as Rosenbusch has already stated, that the parting may occur in the pyroxene of some rocks without the presence of

[1] For a discussion of the eukrites see J. ROTH: Allgemeine und Chemische Geology, II, 1883, p. 200.

[2] Allegemeine und Chemische Geologie, II, p. 185.

twinning lamellae. On the other hand, the pinacoidal parting is entirely absent in cases where twinning lamellae are present. Consequently not much dependence can be placed upon this constituent as a means of distinguishing between gabbros and diabases. The former rocks are evidently related to the latter, whose typically granular, holocrystalline forms they are. Irving,[1] in his work on the geology of the Keweenawan series in Michigan, Wisconsin, and Minnesota, was compelled to make use of coarseness of grain as a means of distinguishing between diabases and gabbros, both of which were thought by him to occur as flows. "It is evident," he writes, "that my observations on these north Wisconsin gabbros bear out the conclusions reached by certain European lithologists, as to the subordinate importance of the foliated condition of augite, by which gabbro is ordinarily separated from diabase, of which it would seem to be merely a phase. Nevertheless, the name is here retained, not only because most of our rock is very close to the typical European gabbros, but more especially because it is so sharply contrasted with the typical Keweenawan diabase that a separate name seems necessary." And again, when speaking of the diabases, he says,[2] "Although grading through coarser kinds into the coarse olivine-gabbros the fine-grained rocks here considered deserve a place by themselves. The gradation into the coarser kinds has never been observed in any one bed, and they are very strongly marked by their external characteristics, both in the fresh and altered states."

The prime distinction between the two classes of rocks is, then, one based upon structure and not upon the difference between the augitic and diallagic nature of its pyroxenic constituent. The structure of the most typical gabbros was recognized by most geologists to be granitic and that of the diabases as ophitic. Professor Judd[3] proposed to restrict the name

[1] Geology of Wisconsin, III, 1880, p. 171.

[2] Copper-Bearing Rocks of Lake Superior, p. 69.

[3] J. W. JUDD: On the Tertiary and older Peridotites of Scotland. Quart. Jour. Geol. Soc., Vol. XLI, 1885, p. 354; and On the Gabbros, Dolerites and Basalts of Tertiary age in Scotland and Ireland. Ib. XLII, 1886, p. 49.

gabbro to granitic forms of plagioclase pyroxene rocks, and to designate as diabases the ophitic, porphyritic and glassy forms. He agrees with Zirkel[1] and Lasaulx[2] in regarding the Hebridean rocks as Tertiary in age, and at the same time as corresponding in all their characteristic features with older augite-plagioclase rocks of granitic structure. These rocks possess not only the structure of the most typical gabbros, but their various constituents are marked by the same microstructure. The plagioclase, olivine, and augite contain the numerous inclusions that were so early recognized as characteristic of these minerals in gabbro, and the latter mineral, the augite, is marked by the diallagic parting, which is the result of the action of a secondary process upon ordinary augite. The process, called by Professor Judd[3] schillerization, is moreover shown to be a function of the depth at which the original rock magma cooled, and the granitic structure of the rock mass is demonstrated to be likewise due to the fact that the rock possessing this structure crystallized at some depth below the earth's surface.

The work of Professor Judd established two great facts, viz.: first, that the age of a rock cannot serve as a basis for rock classification, since it has but little to do with the development of a characteristic structure; and, second, that the geological position of a rock mass is the condition determining not only its structure, but also the peculiar features possessed by its constituents. The rocks which it is proposed to call gabbros are marked by both of the characteristics of deep-seated rocks, while the diabases possess neither of them. The differences between the two groups of rocks, as expressed by their structures, are probably differences that are dependent upon the geological conditions under which they solidified.

[1] Zeits. d. deutsch. Geol. Gesell. XXIII, 1871, pp. 58 and 93.

[2] Min. u. Petrog. Mitth. I, 1878, p. 426.

[3] Cf. also J. W. JUDD: On the Relations between the Solution-planes of Crystals and those of Secondary Twinning; and on the Mode of Development of Negative Crystals along the former. A Contribution to the Theory of Schillerization. Mineralog. Magazine, VII, p. 81.

Professor Rosenbusch[1] clearly appreciated the value of the work on the basic rocks of the Hebrides, for, in the second edition of his Mikroskopische Physiographie, he defines the gabbros as hypidiomorphically granular *plutonic* rocks, consisting of a basic plagioclase, diallage, or a pyroxene resembling diallage, rhombic pyroxenes and often olivine. The important feature in this definition is the characterization of the gabbros as plutonic rocks. The diallage no longer defines the gabbro. The conditions which determined the characteristic structure of the rock at the same time produced the diallagic structure in its pyroxenic constituent. The structure of the typical gabbros, as defined by Rosenbusch, is granular, with the components all equidimensional. Notwithstanding the fact that some plutonic rocks of this class seem to lack the granitic structure, it remains true that the typical gabbro is well described by this definition.

When, however, we seek to separate the gabbros from the diabases we are met at the outset with the same difficulties that have always stood in the way of an exact separation of these two rocks. Rosenbusch[2] describes the diabases as possessing some of the features of plutonic rocks, while at the same time they possess other features that are eminently characteristic of rocks that have flowed out upon the surface of the earth. He nevertheless includes them with the plutonic rocks, stating, however, at the same time that they occur principally as dykes and interbedded flows; are more frequently interstratified with schists than are any other plutonic rocks; and that their predominant structure is the ophitic. That there is a fundamental difference between the two rocks is shown by the fact that the typicial gabbro can not be traced into porphyritic or hyprocrystalline varieties, nor is it ever accompanied by tufas. Whereas the diabases are often porphyritic, and are not infrequently associated with diabasic tufas. A consideration of these phenomena, together with the great differences in the structures of the typical gabbros and diabases, have led Loewinson-Lessing to regard the gabbros as

[1] Mikroskopische Physiographie, der Massigen Gesteine, 2, Auf. 1887, p. 132.

[2] Mikroskopische Physiographie, 2 Auf. II, pp. 174 and 195.

the intrusive[1] equivalents of the diabases, which he thinks were effusive under water, with the augite porphyrites as their equivalent terrestrial effusives. The conclusions of Loewinson-Lessing are not at all startling in their originality, for the wide separation in origin of the two groups of rocks here discussed has been suspected by petrographers ever since the classification of rock-types based on age, mineralogical composition and structure, gave way to the classification founded on geological relationships. The placing of the diabases with the effusive rocks will probably be looked upon with favor by all petrographers, especially since Professor Rosenbusch[2] has treated of them as members of this group in his Heidelberg Lectures, and Brauns[3] has shown that a typical lava flow of a suitable composition may have the diabasic structure developed in it but a few feet below its upper surface.

Lawson,[4] on the other hand, has shown conclusively that the coarse grained, ophitic diabases, interbedded with the Huronian slates and quartzites on the north shore of Lake Superior, are not effusive, but are intrusive, and that their intrusion between the fragmentals with which they are associated, must have occurred at a time when these were deeply buried under a great thickness of overlying rocks. Consequently these coarse, holocrystalline diabases must be regarded as intermediate in their geological relationships, as they are in their structural features between the hypidiomorphic, holocrystalline, plutonic gabbros, and the typically ophitic, hypocrystalline effusive diabases.

But if the hypocrystalline diabases are classed with the effusives, their position with respect to the melaphyres and basalts

[1] F. LOEWINSON-LESSING: Quelques considerations genetiques sur les diabases, les gabbros et les diorites. Bull. d. l. Soc. Belge. de Geol. etc., II, 1888, p. 82.

[2] Cf. Zeits. d. deutsch. geol. Ges. XLI, 1890, p. 533.

[3] R. BRAUNS: Mineralien und Gesteine unf dem hessischem Hinterland II, 3, Diabas mit geflossener Oberflache (Strick oder Gekroselave) von Quotshausen. Zeits. d. deutsch. geol. Ges. XLI, 1890, p. 491.

[4] A. C. LAWSON: The Laccolitic sills of the northwest coast of Lake Superior, Geol. and Nat. Hist. Surv. of Minn. Bull. No. 8, 1893, p. 24.

must be defined. Brauns,[1] in the article referred to in the last footnote, has attempted this correlation. He finds, after reviewing the opinions of various writers on the subject, that "It is not possible to distinguish between diabase and melaphyre on purely petrographical grounds, whether olivine is considered as an essential component of melaphyres, as Rosenbusch holds, or whether it is regarded as unessential in these rocks." In order to construct an exact definition for these three types of rock Brauns is compelled to fall back upon distinctions of age, although Rosenbusch[2] in his last article, in which he refers to this subject, declares it as his opinion that "it requires no great foresight to prophesy that in the not very distant future, this separation [of the effusive rocks into an older and a younger series] will be proven untenable." In spite of the almost certainty that Braun's classification will meet with but little favorable acceptance, it is given here in order to complete the sketch of the history of gabbros and the related rocks. According to Brauns, the basalts are made to include rocks of this class from recent time to the beginning of the Tertiary age. The limit of separation between the melaphyres and the diabases passes through the productive coal measures; rocks older than this are regarded as diabases, while the melaphyres extend from the Carboniferous to the Tertiary. Each group is divided into varieties, according to structure, and into sub-varieties according to mineralogical composition. A tabular grouping of the principal divisions of the effusive rocks of the composition of diabase follows:

	Paleozoic to Productive Coal Measures.	Mesozoic to Tertiary.	Tertiary to Recent.
Granular - - -	Diabase.	Melaphyre.	Basalt.
Porphyritic - -	Diabase-porphyrite.	Melaphyre-porphyrite.	Basalt-porphyrite.
Glassy - - - -	Diabase-glass.	Melaphyre-glass.	Basalt-glass.

It is very evident that the introduction of the diabases among

[1] R. BRAUNS: Ib. 5. Systematik der Diabas, Melaphyr und Basaltgesteine. Ib. p. 532.

[2] H. ROSENBUSCH: Ueber die chemische Beziehungen der Eruptivgesteine. Min. u. Petrog. Mitth. XI, 1890, p. 146.

the effusive rocks has created a disturbance in the melaphyre-basalt group that can only be quieted by the ejection of one of the members of the group, probably the melaphyres, from the position it now occupies. When this is done it is probable that the diabases will take the position thus left vacant, and the plagioclase-augite rocks will be found to occupy these places with respect to each other: the gabbros, the position of a deep seated rock, the diabases that of the corresponding holocrystalline effusive, and the basalt that of the hypocrystalline equivalent.

W. S. BAYLEY.

WATERVILLE, ME., June 1, 1893.